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(54) **ACOUSTIC NOISE REDUCTION IN POWER SUPPLY INDUCTORS**

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(21) Appl. No.: **13/019,233**

(22) Filed: **Feb. 1, 2011**

(65) **Prior Publication Data**

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Related U.S. Application Data

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(51) **Int. Cl.**

H01F 27/29	(2006.01)
H01F 27/02	(2006.01)
G06F 1/16	(2006.01)
H02M 7/00	(2006.01)
G06F 1/26	(2006.01)
H01F 27/33	(2006.01)
H01F 41/02	(2006.01)

(52) **U.S. Cl.**
CPC ***G06F 1/26*** (2013.01); ***H01F 27/33*** (2013.01); *H01F 41/0246* (2013.01); *Y10T 29/4902* (2015.01)

(58) **Field of Classification Search**
CPC H01F 27/33; H01F 27/255; H01F 27/29; H01F 27/30; H01F 27/306; H01F 27/292; H01F 41/0246; H01F 41/10; H01F 3/08; H01F 17/04; H01F 17/041; G06F 1/26; Y10T 29/4902
USPC 336/65, 96, 100, 192, 83; 363/123
See application file for complete search history.

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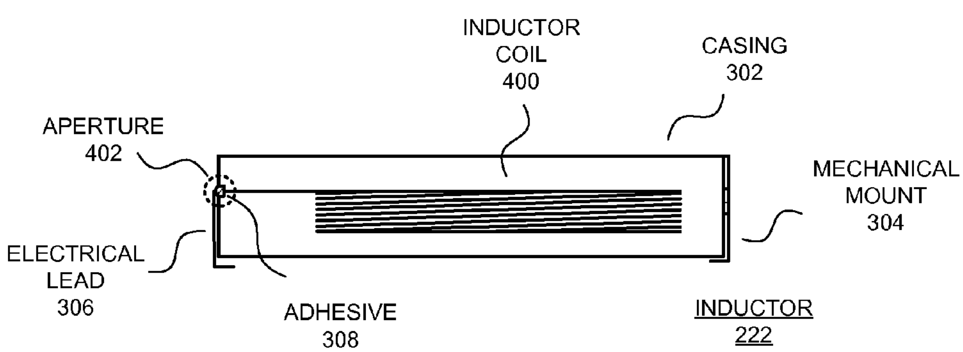
(57) **ABSTRACT**

Embodiments of the present invention provide an apparatus that reduces an audible noise produced in a power supply. The apparatus includes: (1) a housing; (2) an inductor coil formed from a coil of wire enclosed in the housing; (3) a set of wires that are coupled from the inductor coil to the outside of the housing through corresponding apertures in the housing, comprising electrical leads for the inductor coil; and (4) a predetermined amount of adhesive in the apertures that bonds the wires to the housing to reduce an audible noise produced when the current through the inductor coil is cycled quickly.

11 Claims, 7 Drawing Sheets



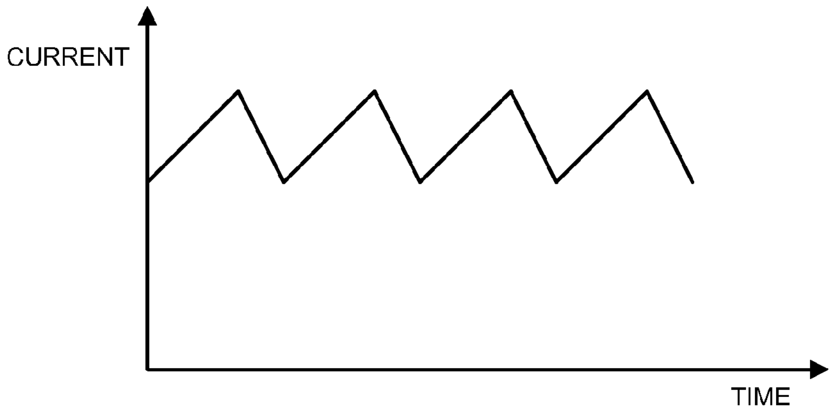


FIG. 1A

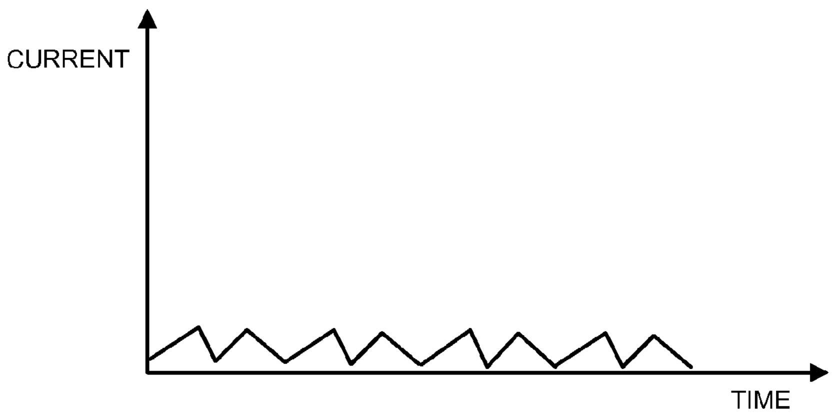


FIG. 1B

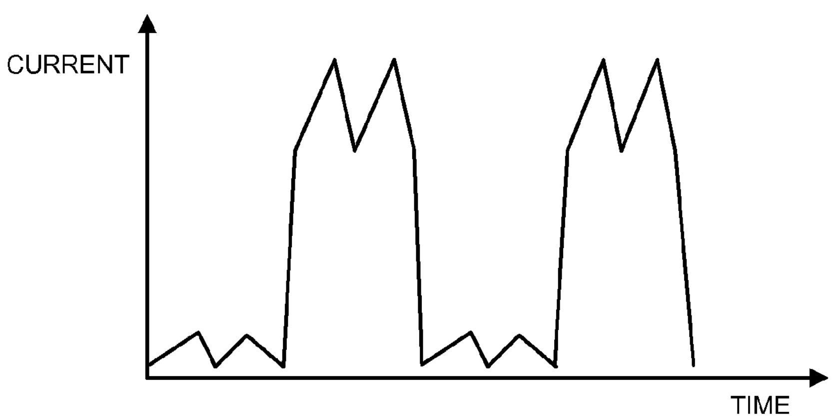


FIG. 1C

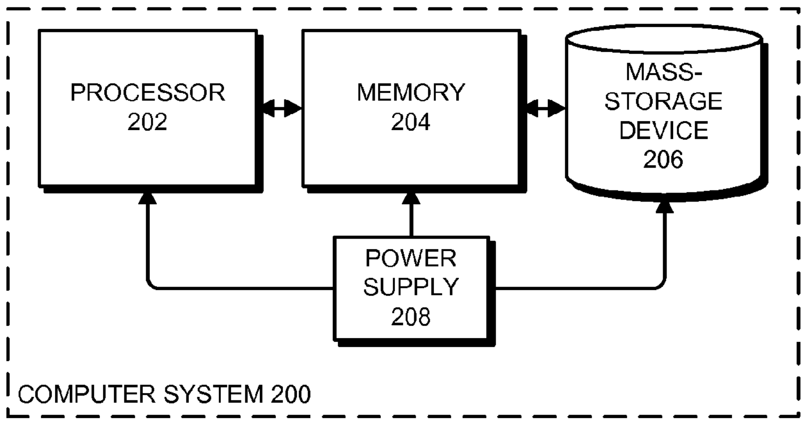

PROCESSOR
202
MEMORY
204
MASS-
STORAGE
DEVICE
206
POWER
SUPPLY
208
COMPUTER SYSTEM 200

FIG. 2A

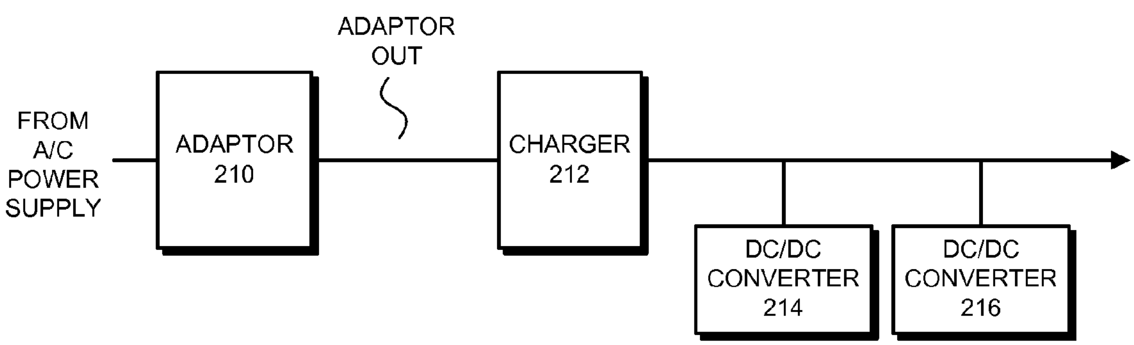

FROM
A/C
POWER
SUPPLY
ADAPTOR
210
ADAPTOR
OUT
CHARGER
212
DC/DC
CONVERTER
214
DC/DC
CONVERTER
216

FIG. 2B

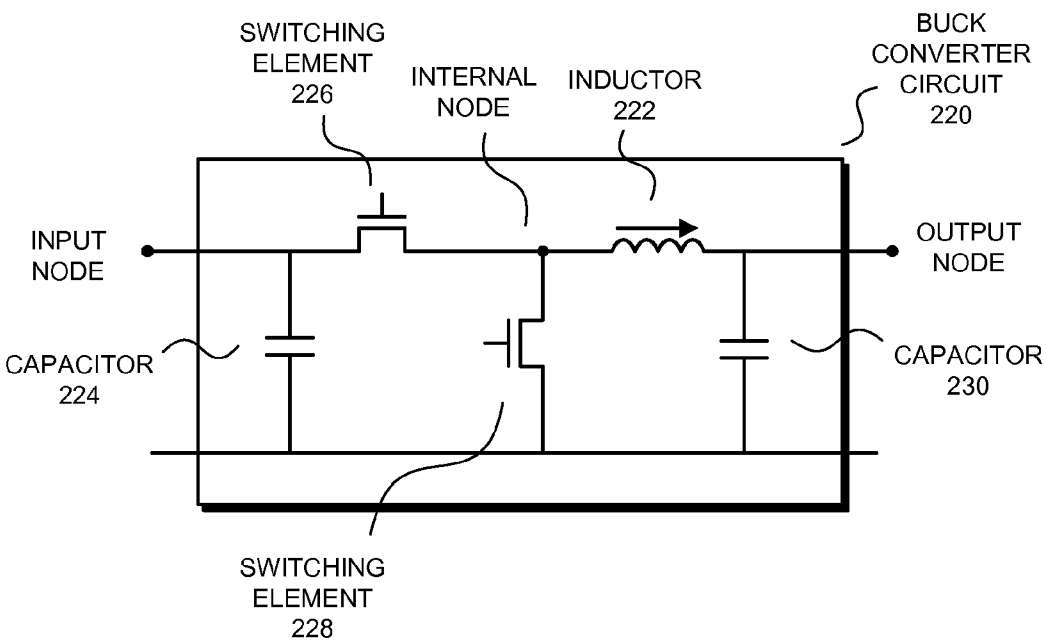

SWITCHING
ELEMENT
226
INTERNAL
NODE
INDUCTOR
222
BUCK
CONVERTER
CIRCUIT
220
INPUT
NODE
OUTPUT
NODE
CAPACITOR
224
CAPACITOR
230
SWITCHING
ELEMENT
228

FIG. 2C

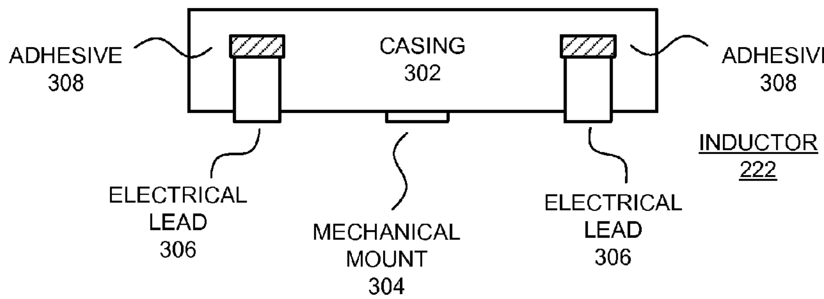


FIG. 3A

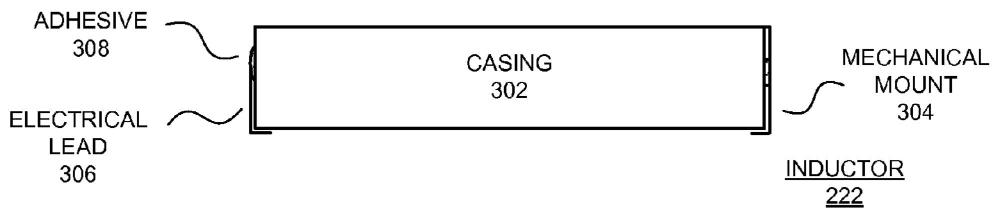


FIG. 3B

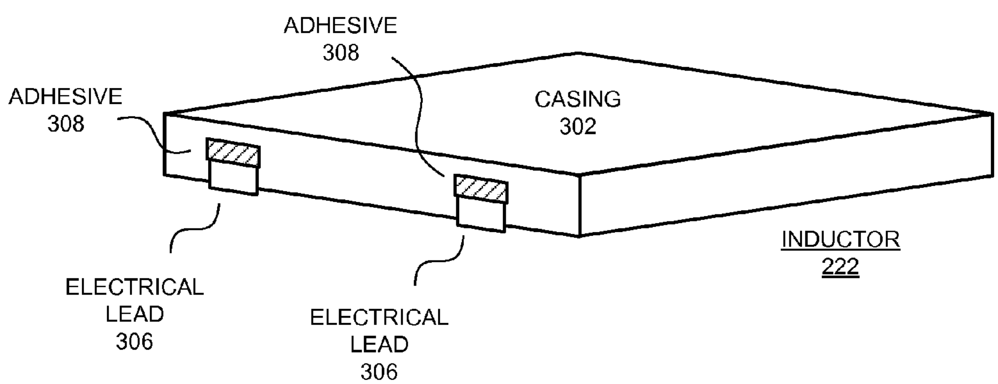


FIG. 3C

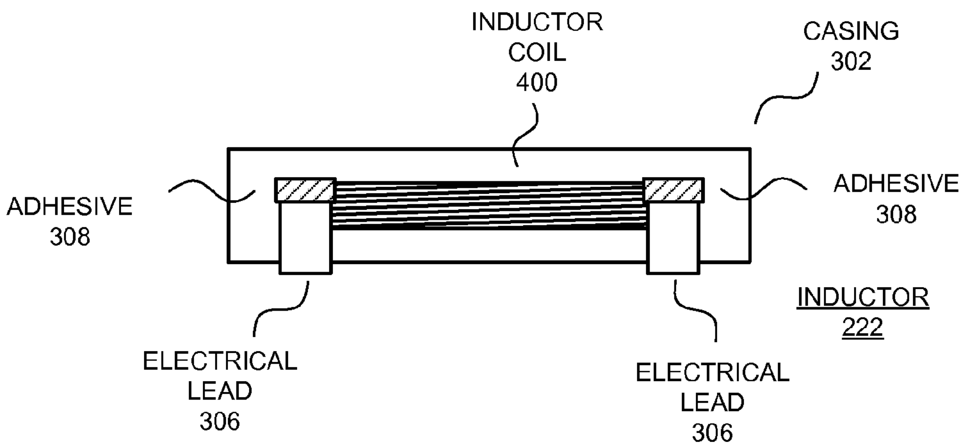

INDUCTOR
COIL
400
CASING
302
ADHESIVE
308
ADHESIVE
308
INDUCTOR
222
ELECTRICAL
LEAD
306
ELECTRICAL
LEAD
306

FIG. 4A

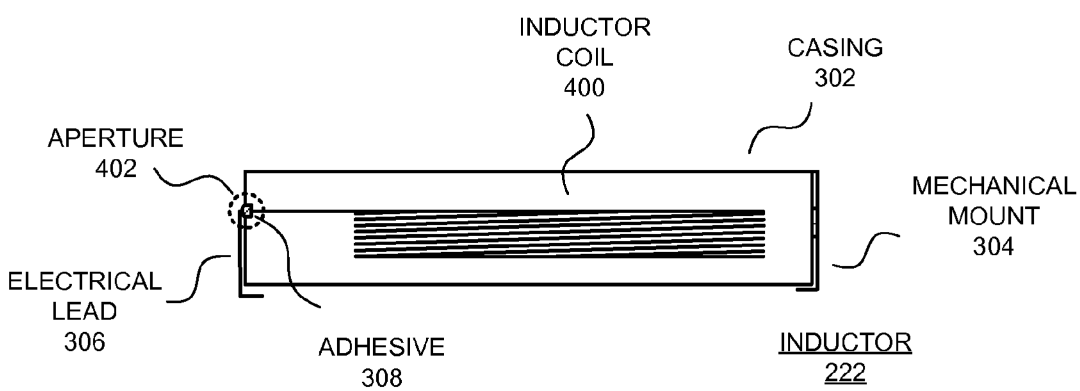

INDUCTOR
COIL
400
CASING
302
APERTURE
402
MECHANICAL
MOUNT
304
ELECTRICAL
LEAD
306
ADHESIVE
308
INDUCTOR
222

FIG. 4B

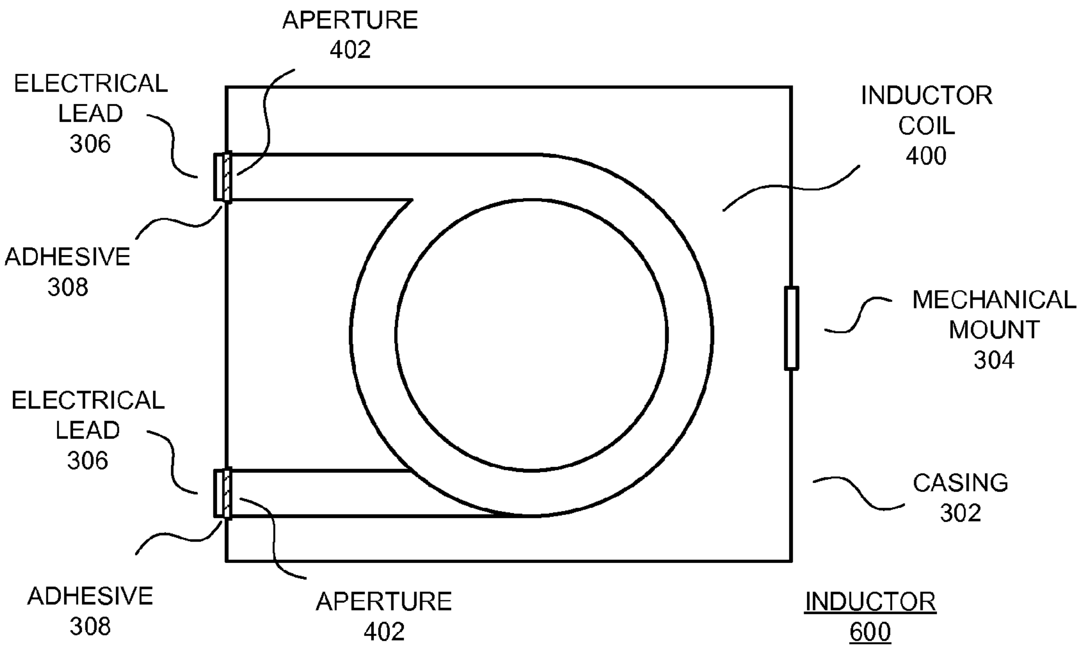

APERTURE
402
ELECTRICAL
LEAD
306
INDUCTOR
COIL
400
ADHESIVE
308
MECHANICAL
MOUNT
304
ELECTRICAL
LEAD
306
CASING
302
ADHESIVE
308
APERTURE
402
INDUCTOR
600

FIG. 4C

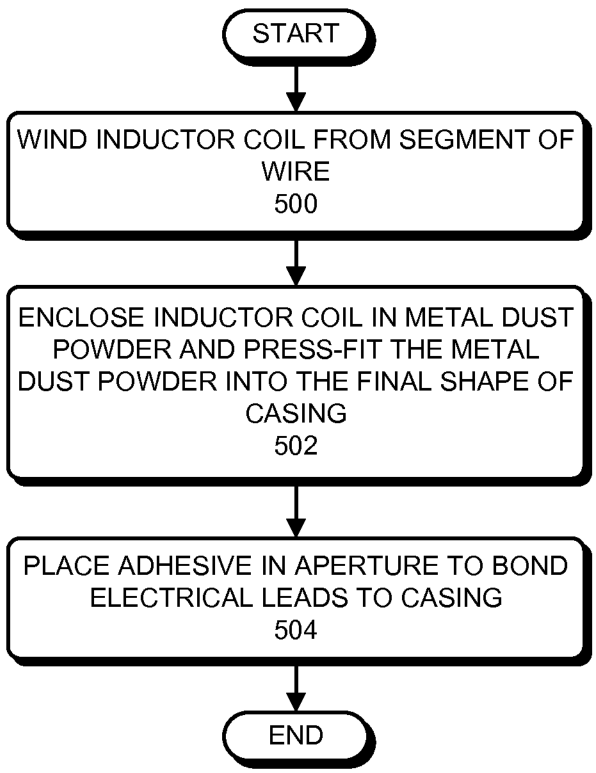

START
WIND INDUCTOR COIL FROM SEGMENT OF WIRE
500
ENCLOSE INDUCTOR COIL IN METAL DUST POWDER AND PRESS-FIT THE METAL DUST POWDER INTO THE FINAL SHAPE OF CASING
502
PLACE ADHESIVE IN APERTURE TO BOND ELECTRICAL LEADS TO CASING
504
END

FIG. 5

ACOUSTIC NOISE REDUCTION IN POWER SUPPLY INDUCTORS

RELATED APPLICATIONS

This application is a divisional application of, and hereby claims priority under 35 U.S.C. §120 to, pending U.S. patent application Ser. No. 11/875,695, entitled "Acoustic Noise Reduction in Power Supply Inductors," filed 19 Oct. 2007, by Dayu Qu.

BACKGROUND

1. Field of the Invention

Embodiments of the present invention relate to electronic circuits and power supplies. More specifically, embodiments of the present invention relate to techniques for reducing acoustic noise from power supply inductors.

2. Related Art

Many modern computer systems operate under strict power consumption limitations. In order to meet these limitations, some computer systems support one or more low-power modes in which some of the computer's components operate using less power or are disabled. For example, during a low-power mode, the computer system's hard drives can be stopped, the display can be deactivated, and/or the CPU clock can be slowed down.

When operating in full-power mode, the computer system draws current from a power supply according to the load on the computer system. For example, FIG. **1**A presents a graph illustrating a current-flow pattern during full-power mode. As can be seen from FIG. **1**A, the computer system draws different levels of power for different loads. For example, when a user loads a program from disk into memory, the disk, the memory, and the CPU are all activated. Hence, power usage increases, which increases the current drawn from the power supply. When the computer system subsequently finishes loading the program from disk, there is a corresponding decrease in the current drawn from the power supply.

When operating in low-power mode, the computer system can disable all but a minimal subset of computer system components. For example, the low-power mode may be a "sleep mode," wherein all components are deactivated except a hardware monitor that is designed to wake the computer system upon receiving a communication from a peripheral (e.g., a keystroke or mouse movement). During the low-power mode, the computer system draws a small fraction of the power drawn during full-power mode. For example, FIG. **1**B presents a graph illustrating a current-flow pattern during a low-power mode.

Some computer systems support a hybrid mode, which limits power consumption by dynamically disabling and re-enabling computer system components and features as they are used. Although the components and features are sometimes disabled in the hybrid mode, the computer system appears to be fully functional. For example, in some hybrid modes, the computer system may slow down the CPU clock when a user is not performing operations that require the full CPU power. In some systems, during the hybrid mode the computer system cycles between a specialized low-power mode and full-power mode at every opportunity (e.g., between keystrokes). For example, FIG. **1**C presents a graph illustrating a current-flow pattern during a hybrid low-power/full-power mode. As shown in FIG. **1**C, the computer system is subject to significant current swings during the hybrid mode (i.e., high di/dt).

Unfortunately, some computer systems include parts in the power supply that perform inadequately during such hybrid modes. For example, in some power supplies, an inductor will produce a clearly audible whine caused by the high di/dt when cycling back and forth between low-power mode and full-power mode. Because there are often limitations on the noise that computer systems (particularly laptops) may emit, an audible whine from the power supply may be unacceptable.

Hence, what is needed is a power supply for a computer system without the above-described problem.

SUMMARY

Embodiments of the present invention provide an apparatus that reduces an audible noise produced in a power supply. The apparatus includes: (1) a casing; (2) an inductor coil formed from a coil of wire enclosed in the casing; (3) a set of wires that are coupled from the inductor coil to the outside of the casing through corresponding apertures in the casing comprising electrical leads for the inductor coil; and (4) a predetermined amount of adhesive in the apertures that bonds the wires to the casing to reduce an audible noise produced when the current through the inductor coil is cycled quickly.

In some embodiments, the set of wires extend along the casing from the corresponding set of apertures and under the casing alongside an outside surface of the casing forming "J" leads for coupling the inductor coil to an electrical circuit.

In some embodiments, a mechanical mount is coupled to the outside of the casing on an opposite side of the casing from the set of apertures.

In some embodiments, the casing is formed by press-fitting metal dust powder around the inductor coil.

Embodiments of the present invention provide a method for manufacturing an inductor for reducing an audible noise in an electrical circuit. During the process, an inductor coil is first wound from a segment of wire. Next, the wound inductor coil is enclosed in metal dust powder. The metal dust powder is then press-fit into a casing for the inductor, wherein a set of wires are coupled from the inductor coil to the outside of the casing through a corresponding set of apertures in the casing (to serve as electrical leads for the inductor coil). Next, a predetermined amount of adhesive is placed in the apertures to bond the wires to the casing to reduce an audible noise produced when the current through the circuit element is cycled quickly.

Embodiments of the present invention provide a computer system for reducing an audible noise produced in a power supply. The computer system includes a processor and a power supply that provides power to the processor. The power system includes: (1) a casing; (2) an inductor coil formed from a coil of wire enclosed in the casing; (3) a set of wires that are coupled from the inductor coil to the outside of the casing through corresponding apertures in the casing, wherein the wires form electrical leads for the inductor coil; and (4) a predetermined amount of adhesive in the apertures that bonds the wires to the casing to reduce an audible noise produced when the current through the inductor coil is cycled quickly.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1**A presents a graph illustrating a current-flow pattern during a full-power mode in a computer system.

FIG. **1**B presents a graph illustrating a current-flow pattern during a low-power mode in a computer system.

FIG. **1**C presents a graph illustrating a current-flow pattern during a hybrid low-power/full-power mode.

FIG. 2A presents a block diagram of a computer system in accordance with embodiments of the present invention.

FIG. 2B presents a block diagram of a power supply in a computer system in accordance with embodiments of the present invention.

FIG. 2C presents a circuit diagram illustrating a buck converter circuit in accordance with embodiments of the present invention.

FIG. 3A presents a front view of an inductor in accordance with embodiments of the present invention.

FIG. 3B presents a side view of an inductor in accordance with embodiments of the present invention.

FIG. 3C presents an isometric view of an inductor in accordance with embodiments of the present invention.

FIG. 4A presents a front view of an inductor with a casing partially cut-away to reveal the inductor coil in accordance with embodiments of the present invention.

FIG. 4B presents a side view of an inductor with a casing partially cut-away to reveal the inductor coil in accordance with embodiments of the present invention.

FIG. 4C presents a top view of an inductor with a casing partially cut-away to reveal the inductor coil in accordance with embodiments of the present invention.

FIG. 5 presents a flowchart illustrating a method of manufacturing an inductor in accordance with embodiments of the present invention.

DETAILED DESCRIPTION

The following description is presented to enable any person skilled in the art to make and use the invention, and is provided in the context of a particular application and its requirements. Various modifications to the disclosed embodiments will be readily apparent to those skilled in the art, and the general principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the present invention. Thus, the present invention is not limited to the embodiments shown, but is to be accorded the widest scope consistent with the claims.

Computer System

FIG. 2A presents a block diagram of a computer system **200** in accordance with embodiments of the present invention. Computer system **200** includes processor **202**, memory **204**, and mass-storage device **206**. Computer system **200** also includes power supply **208**, which supplies electrical power to processor **202**, memory **204**, mass-storage device **206**, and other components in computer system **200** (not shown)

In some embodiments of the present invention, computer system **200** is a general-purpose computer system that supports low-power modes, including sleep, idle, and/or standby modes. During these low-power modes, some or all of the functions and/or components of computer system **200** are slowed down or disabled to conserve power. For example, when operating in a low-power mode, computer system **200** may slow down or disable processor **202**, memory **204**, mass-storage device **206**, and/or other devices such as monitors and peripheral devices (not shown).

In embodiments of the present invention, computer system **200** also supports one or more "hybrid" modes in which computer system **200** appears to be in full-power mode, but instead dynamically switches from a full-power mode to one or more special low-power modes as conditions permit. For example, computer system **200** may slow down the CPU clock and/or other system clocks whenever the load on the CPU and other components is low, but may restore the CPU clock and/or other system clocks when the load increases. In some embodiments, computer system **200** can enter and exit a special low-power mode very rapidly, facilitating a nearly continuous switch between the modes. For example, when a user is editing a document, computer system **200** may generally operate in full-power mode, but as often as between keystrokes computer system **200** may enter the specialized low-power mode.

In FIG. 2A, processor **202** is a central processing unit (CPU) that processes instructions for computer system **200**. For example, processor **202** can be a microprocessor, a device controller, or other type of computational engine. Memory **204** is volatile memory that stores instructions and data for processor **202** during operation of computer system **200**. For example, memory **204** can include DRAM, SDRAM, or another form of volatile memory. Mass-storage device **206** is a non-volatile storage device that stores instructions and data for processor **202**. For example, mass-storage device **206** can be a hard disk drive, a flash memory, an optical drive, or another non-volatile storage device.

Note that although we describe embodiments of the present invention using computer system **200**, alternative embodiments can be used within other types of computing systems. Moreover, embodiments of the present invention are operable in any type of electronic device wherein a circuit element produces an audible noise caused by significant di/dt.

Power Supply

FIG. 2B presents a block diagram of a power supply in computer system **200** in accordance with embodiments of the present invention. The power supply includes adaptor **210**, charger **212**, and a set of DC/DC converters **214** and **216** (i.e., voltage regulators).

Adapter **210** converts an AC signal from a power source (e.g., a common 120 VAC electrical outlet) to a 16.5 VDC signal which is in turn converted by charger **212** into a 12.6 VDC signal. The 12.6 VDC signal is then used as an input for DC/DC converters **214**. The 12.6 VDC signal can also be used to charge a battery (not shown) if there is a battery present in the system.

FIG. 2C presents a circuit diagram illustrating a buck converter circuit **220** in accordance with embodiments of the present invention. Buck converter circuit **220** is a switched-mode step-down DC-to-DC converter. Note that charger **212** includes a buck converter circuit **220**.

Buck converter circuit includes inductor **222**, capacitors **224** and **230**, and switching elements **226** and **228**. The operation of the circuit elements in the buck circuit is known in the art, hence a more detailed description is not provided. Note that in some embodiments of the present invention, both switching element **226** and **228** are transistors. However, in alternative embodiments, switching element **226** is a transistor while switching element **228** is a diode or another such circuit element.

Inductor

FIG. 3A-3C present front, side, and isometric external views of an inductor **222** in accordance with embodiments of the present invention. Inductor **222** includes casing **302**, electrical leads **306**, and mechanical mount **304**.

In some embodiments of the present invention, casing **302** is formed from press-fit metal dust powder. In these embodiments, inductor coil **400** (see FIG. 4) is formed from a segment of wire. Inductor coil **400** is then enclosed in metal dust powder, which is pressed into the final shape of casing **302**. When pressing the metal dust powder around inductor coil **400**, a pressure of several tons of force per square inch is used. Although there are multiple forms of metal dust powder that may be used to form casing **302**, forming an inductor casing from metal dust powder is known in the art and is therefore not described in more detail. Note that although we describe embodiments of the present invention that use press-fitting to form the casing, alternative embodiments use sintering or other techniques to form the casing from the metal dust powder.

In some embodiments, casing **302** is a small-outline j-lead (SOJ) package for surface-mounting inductor **222**. Hence, as shown in FIGS. **3A-3C**, electrical leads **306** extend out of an aperture in the side of casing **302**, then run alongside casing **302**, and under casing **302** as shown in FIG. **3B** (i.e., the leads appear as a "J"). In addition, mechanical mount **304** is bonded to the outside of casing **302** on the opposite side of casing **302** from electrical leads **306**. Mechanical mount **304** runs alongside casing **302**, and under casing **302** as shown in FIG. **3B** (i.e., also appearing as a "J"). Note that although we describe embodiments of the present invention using the SOJ package, in alternative embodiments, casing **302** is in another packaging format.

When placed in an electrical circuit, inductor **222** is mounted by bonding (e.g., soldering) electrical leads **306** and mechanical mount **304** to a mounting surface. In some embodiments of the present invention, mechanical mount **304** has no electrical function and serves only as a third mounting point for inductor **222** in order to provide mechanical stability.

Inductor **222** also includes adhesive **308** on electrical leads **306**. During manufacture, adhesive **308**, initially liquid, is placed in aperture **402** (see FIG. **4B**) from which electrical leads **306** extend out of casing **302**. Adhesive **308** then sets, bonding the electrical leads **306** to one or more walls of aperture **402**. By bonding electrical leads **306** to casing **302** in this way, a significant reduction in acoustic noise is achieved.

Adhesive **308** can be any adhesive used to bond electrical parts to one another. Such adhesives are known in the art. In some embodiments of the present invention, the adhesive is Chemiseal E-1358B from the Chemitech Inc. of Tokyo, Japan.

FIGS. **4A-4C** present front, side, and top partially cut-away views of inductor **222** in accordance with embodiments of the present invention. In the front view in FIG. **4A**, inductor coil **400** can be seen within casing **302** (although inductor coil **400** is partially obscured by electrical leads **306**).

In the side view in FIG. **4B**, an electrical lead **306** can be seen extending from inductor coil **400** out of aperture **402** in casing **302** and around casing **302** in the "J"-shape described above. Adhesive **308** bonds electrical lead **306** to one or more walls of aperture **402** in casing **302**. Bonding electrical leads **306** to the walls of aperture **402** stabilizes electrical leads **306**, which minimizes the movement of electrical leads **306** when inductor **222** experiences high di/dt during the hybrid mode. Minimizing the movement of electrical leads **306** reduces the acoustic noise that might otherwise be produced by inductor **222**.

In the top view in FIG. **4C**, inductor coil **400**'s circular shape is visible with electrical leads extending from inductor coil out of aperture **402** in casing **302**. Also shown is adhesive **308**, which bonds electrical leads **306** within aperture **402**.

Note that in some embodiments of the present invention, casing **302** may not include aperture **402**. In these embodiments, electrical leads **306** extend directly out of the side of casing **302** and adhesive **308** can be a drop on the surface of casing **302** that surrounds electrical lead **306** (and bonds electrical lead **306** to casing **302**).

Manufacturing Process

FIG. **5** presents a flowchart illustrating a method of manufacturing an inductor in accordance with embodiments of the present invention. The process starts when inductor coil **400** is wound from a segment of wire (step **500**). Inductor coil **400** is then enclosed by metal dust powder, which is press-fit into the final shape of casing **302** (step **502**). When step **502** is complete, electrical leads **306** extend from inductor coil **400** within casing **302** out of aperture **402** and around casing **302** in the "J"-shape described above.

Next, adhesive **308** is placed in aperture **402** in order to bond electrical leads **306** to casing **302** (step **504**).

Alternative Embodiments

In some embodiments of the present invention, inductor **222** is entirely covered with adhesive **308**. In these embodiments, as with embodiments where the adhesive is only placed in aperture **402**, adhesive **308** bonds electrical leads **306** to casing **302** (as described above). These embodiments incur the cost of the additional adhesive to avoid the manufacturing step of precisely placing the correct amount of adhesive directly in apertures **402**.

In some embodiments, inductor **222** is mounted by adhesively bonding the center of casing **302** to a mounting surface along with soldering or otherwise bonding electrical leads **306** and mechanical mount **304** to the mounting surface. By adhesively bonding the center of casing **302**, acoustic noise is further reduced.

The foregoing descriptions of embodiments of the present invention have been presented only for purposes of illustration and description. They are not intended to be exhaustive or to limit the present invention to the forms disclosed. Accordingly, many modifications and variations will be apparent to practitioners skilled in the art. Additionally, the above disclosure is not intended to limit the present invention. The scope of the present invention is defined by the appended claims.

What is claimed is:

1. A power supply, comprising:

an adaptor that receives an alternating-current (AC) input signal and outputs a direct-current (DC) output signal, wherein the adaptor electrically converts the AC input signal to the DC output signal;

a charger coupled to the output of the adaptor, wherein the charger electrically converts the DC output signal to a lower-voltage DC signal and outputs the lower-voltage DC signal;

wherein the charger includes an inductor in a J-lead package, wherein a set of wires forming a set of J-leads are coupled from the inductor coil enclosed in the J-lead package to the outside of the J-lead package through corresponding apertures in a casing;

wherein each wire is bonded to a set of walls of the corresponding aperture using a bonding agent.

2. The power supply of claim **1**, further comprising a set of DC-to-DC converters coupled to the output of the charger, wherein each DC-to-DC converter converts the lower-voltage DC signal to a DC signal at a predetermined voltage level.

3. The power supply of claim **1**, wherein the J-lead package is formed by press-fitting metal dust powder around the inductor coil or by enclosing the inductor coil in metal dust powder and sintering.

4. The power supply of claim **1**, wherein the bonding agent is a bonding agent used to bond electrical components.

5. A computer system, comprising:

a processor;

a power supply that provides power to the processor, comprising:

an adaptor that receives an alternating-current (AC) input signal and outputs a direct-current (DC) output signal, wherein the adaptor electrically converts the AC input signal to the DC output signal;

a charger coupled to the output of the adaptor, wherein the charger electrically converts the DC output signal to a lower-voltage DC signal and outputs the lower-voltage DC signal;

wherein the charger includes an inductor in a J-lead package, wherein a set of electrical leads forming a set of J-leads are coupled from the inductor coil enclosed in the J-lead package to the outside of the J-lead package through corresponding apertures in a casing;

wherein each electrical lead is bonded to a set of walls of the corresponding aperture using a bonding agent.

6. The computer system of claim **5**, wherein the electrical leads extend along the casing from their corresponding apertures in the casing and under the casing alongside an outside surface of the casing, forming electrical connections for coupling the inductor to an electrical circuit.

7. The computer system of claim **5**, further comprising a mechanical mount coupled to the outside of the casing on an opposite side of the casing from the apertures on the casing.

8. The computer system of claim **5**, wherein the casing is formed by press-fitting metal dust powder around the inductor coil.

9. The computer system of claim **5**, wherein the casing is formed by shaping and sintering metal dust powder around the inductor coil.

10. The computer system of claim **5**, wherein the electrical leads are bonded with a bonding agent used to attach electrical components to one another.

11. The computer system of claim **5**, wherein the power supply further comprises a set of DC-to-DC converters coupled to the output of the charger, wherein each DC-to-DC converter converts the lower-voltage DC signal to a DC signal at a predetermined voltage level.

* * * * *